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6. Zeeman effect. Energy and wavefunction correction

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In a weak magnetic field $\mathbf{B} = B\hat{z}$, the perturbation Hamiltonian is:

$$H' = \frac{e}{2m}(\mathbf{L} + g_s\mathbf{S}) \cdot \mathbf{B},$$

with $g_s \approx 2$ and $\mu_B = \frac{e\hbar}{2m}$. The first-order energy correction for a state $|n, \ell, s, j, m_j\rangle$ is:

$$\Delta E^{(1)} = \mu_B g_j m_j B,$$

where the Landé g-factor is:

$$g_j = 1 + \frac{j(j+1) + s(s+1) - \ell(\ell+1)}{2j(j+1)}.$$

The wavefunction correction is:

$$|\psi^{(1)}\rangle = \sum_{n' \neq n} \frac{\langle n'|H'|n\rangle}{E_n^{(0)} - E_{n'}^{(0)}} |n'\rangle,$$

a standard first-order perturbative expansion mixing nearby states.

12. Einstein's theory of radiation

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Einstein introduced transition rates between two levels E_1 and E_2:

Spontaneous emission:

$$P_{spont} = A_{21},$$

Induced emission:

$$P_{ind} = B_{21}\rho(\nu),$$

Absorption:

$$P_{abs} = B_{12}\rho(\nu),$$

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where $\rho(\nu)$ is the energy density of the radiation field.

Spontaneous emission is due to vacuum fluctuations and always results in photon emission. It is not related to absorption. In thermal equilibrium:

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}, \quad B_{12} = B_{21}.$$

13. Spin-statistics theorem

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The spin-statistics connection states that particles with integer spin (bosons) have symmetric total wavefunctions and obey Bose–Einstein statistics. Particles with half-integer spin (fermions) have antisymmetric total wavefunctions and obey Fermi–Dirac statistics.

Spin determines the symmetry of multiparticle wavefunctions. Fermions (electrons) cannot occupy the same state (Pauli exclusion), while bosons can (photons in a laser beam).

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